CDF/ANAL/EXOTIC/PUBLIC/8390

Search for Standard Model Higgs Boson Production in Association with $W^{\pm}$ Boson at CDF with 1 fb^{-1}

The CDF Collaboration
URL http://www-cdf.fnal.gov
(Dated: July 22, 2006)

We present a search for Standard Model Higgs boson production in association with a $W^{\pm}$ boson. This search uses data corresponding to an integrated luminosity of $955\,\mathrm{pb}^{-1}$. We perform two distinct b tagging selections in the W+jets sample, the first with exactly one secondary vertex tag passing a neural network filter, and the second with at least two vertex-tagged jets. The number of tagged events and the resulting dijet mass distributions are consistent with the Standard Model expectations, and we set an upper limit on the WH production cross section times branching ratio $\sigma(p\bar{p} \to W^{\pm}H) \times BR(H \to b\bar{b}) < 3.9 \sim 1.3$ pb for Higgs masses from 110 GeV/c^2 to 150 GeV/c^2 at 95% confidence level.

Preliminary Results for Summer 2006 Conferences

I. INTRODUCTION

The success of the Standard Model in explaining and predicting experimental data provides strong motivation for the existence of a neutral Higgs boson. Current electroweak fits combined with direct searches from LEP2 indicate the mass of the Higgs boson is less than $207\,\mathrm{GeV}/c^2$ at 95% confidence level [1, 2].

In proton-antiproton collisions of $\sqrt{s} = 1.96\,\mathrm{TeV}$ at the Tevatron, the Standard Model Higgs boson may be produced in association with a W boson [3]. For low Higgs masses (below $140\,\mathrm{GeV}/c^2$) the dominant decay mode is $H \to b\bar{b}$. The final state from the WH production is therefore $\ell\nu b\bar{b}$, where the high-p_T lepton from the W decay provides an ideal trigger signature.

The previously published WH search from CDF [4] was performed in a dataset with integrated luminosity equivalent to $320\,\mathrm{pb}^{-1}$. This analysis uses about 3 times of the previous data and employs a neural network b-tagging algorithm designed to reduce background contamination from events with charm or light-flavor jets.

II. DATA SAMPLE & EVENT SELECTION

We use data collected through February 2006, corresponding to an integrated luminosity of $955\,\mathrm{pb}^{-1}$. The events are collected by the CDF II detector with high-p_T electron or muon triggers which have an $18\,\mathrm{GeV}$ [5]. The electron or muon is further required to be isolated with E_T (or p_T) $> 20\,\mathrm{GeV}$.

Events having the W+jets signature are confirmed with a missing transverse energy requirement ($\not{E}_T > 20\,\mathrm{GeV}$). The events are classified according to the number of jets having $E_T > 15\,\mathrm{GeV}$ and $|\eta| < 2.0$. Because the Higgs boson decays to $b\bar{b}$ pairs, we employ a b-tagging algorithm which relies on the long lifetime and large mass of the b quark.

A. Secondary Vertex Tagging Algorithm

Secondary vertices are identified in jets by fitting tracks displaced from the primary vertex. This method has been used in other Higgs searches and top analyses [4, 6].

The neural network b-tagger (NN b-tag) builds on the existing secondary vertex tagger to separate b jets from c and l (light) flavor jets. Jet variables which provide discrimination for b jets are combined into two neural networks using the JETNET package [7]. The input variables give information about either the secondary vertex (transverse decay length, number of tracks in the vertex, the fit χ^2, vertex mass) or the jet itself (number of tracks in the jet, number of displaced tracks in the jet, cumulative displacement probability for all displaced tracks). These networks are trained on and applied to events which have been already tagged by the secondary vertex algorithm.

The tagger employs two neural networks in series. One is trained to separate b jets from light-flavor jets, and the other, b from c. Jets which pass a cut on both neural network output values are accepted by the tagger. The cut value is tuned so that the neural networks are 90% efficient for b jets which have an identified displaced secondary vertex. We have studied the jet rejection at these cut values, and find that we reject 65% of light-flavor jets and about 50% of the c jets.

B. Total WH Acceptance

The signal acceptance is measured in a sample of Monte Carlo events generated with the PYTHIA program [10]. The detection efficiency for signal events is defined as:

$$\epsilon_{WH\to l\nu b\bar{b}} = \epsilon_{Z0} \cdot \epsilon_{trig} \cdot \epsilon_{leptonid} \cdot \epsilon_{iso} \cdot \epsilon^{MC}_{WH\to\ell\nu b\bar{b}} \cdot \left(\sum_{l'=e,\mu,\tau} Br(W \to \ell\nu) \right), \tag{1}$$

where $\epsilon^{MC}_{WH\to\ell\nu b\bar{b}}$ is the fraction of signal events (with $|z_0| < 60\,\mathrm{cm}$) which pass the kinematic requirements. The effect of the b-tagging scale factor in this fraction is included by randomly selecting tagged jets. The quantity ϵ_{Z0} is the efficiency of the $|z_0| < 60\mathrm{cm}$ cut; ϵ_{trig} is the trigger efficiency for high p_T leptons; $\epsilon_{leptonid}$, is the efficiency to identify a lepton; ϵ_{iso} is efficiency of the energy isolation cut ; and $Br(W \to \ell\nu)$ is the branching ratio for leptonic W decay.

Fig. 1 shows the overall acceptance for each b-tagging condition − including all systematic effects − as a function of Higgins mass. The acceptance increases linearly from (1.3±0.096)% to (1.5±0.11)% as a function of Higgs mass for at exactly one secondary vertex tag confirmed with NN b-tagging. The acceptances for the tight secondary vertex double-tagged selection range from (0.47±0.078)% to (0.56±0.094)%.

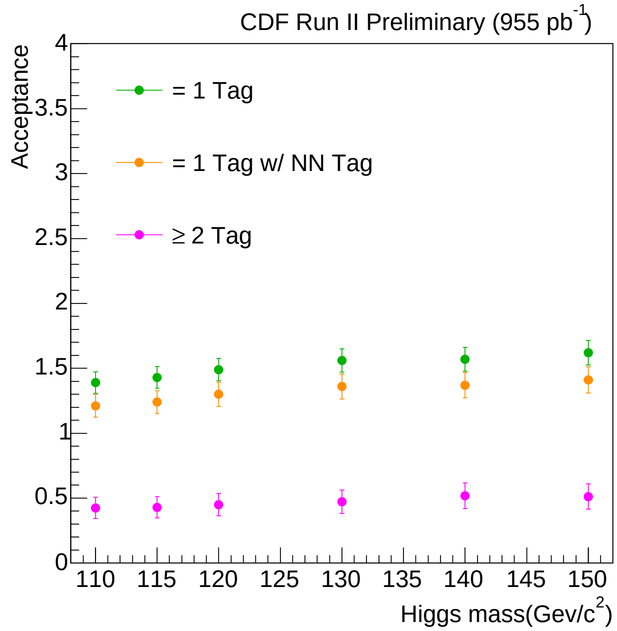

FIG. 1: Calculated WH acceptance for different b-tagging selection criteria. The final results combine the ≥ 2 tag and $= 1$ tag w/ NN tag selections.

III. BACKGROUNDS

This analysis builds on the method of background estimation detailed in Ref. [6]. In particular, the contributions from the following individual backgrounds are calculated: falsely b-tagged events, W production with heavy flavor quark pairs, QCD events with false W signatures, top quark pair production, and electroweak production (diboson, single top).

We estimate the number of falsely b-tagged events by counting the number of negatively-tagged events, that is, events in which the measured displacement of the secondary vertex is opposite the b jet direction. Such negative tags are due to tracking resolution limitations, but they provide a reasonable estimate of the number of false positive tags after a correction for material interactions and long-lived light flavor particles.

The number of events from W + heavy flavor is calculated using information from both data and Monte Carlo programs. We calculate the fraction of W events with associated heavy flavor production in the ALPGEN Monte Carlo program interfaced with the HERWIG parton shower code [8, 9]. This fraction and the tagging efficiency for such events are applied to the number of events in the original W+jets sample after correcting for the $t\bar{t}$ and electroweak contributions.

We constrain the number of QCD events with false W signatures by assuming the lepton isolation is independent of $\not\!\!E_T$ and measuring the ratio of isolated to non-isolated leptons in a $\not\!\!E_T$ sideband region. The result in the tagged sample can be calculated in two ways: by applying the method directly to the tagged sample, or by estimating the number of non-W QCD events in the pretag sample and applying an average b-tagging rate.

The summary of the background contributions to the exactly 1 NN b-tag selection is given in Table I, and the summary in the case of double-tagged events is shown in Table II. Because the expected number of Higgs signal events is small in the 1-,3-, and 4-jet bins, the good agreement between predicted backgrounds and observed data in Fig. 2 gives us confidence in our overall background estimate.

IV. SYSTEMATIC UNCERTAINTIES

The uncertainties on the signal acceptance currently have the largest effect on the Higgs sensitivity. The b-tagging uncertainty is dominated by the uncertainty on the data/MC scale factor $S = 0.891 \pm 0.071$ (stat.+ sys.). An additional scale factor and systematic for the b-tagging neural network is measured to be $S_{\rm NN} = 0.97 \pm 0.02$ in a jet data sample. The uncertainties due to initial state radiation and final state radiation are estimated by changing the parameters

Jet Multiplicity	1jet	2jet	3jet	$\geq$ 4jet
Observed Events(Before b-tagging)	94051	14604	2362	646
Mistag	139.7 $\pm$ 27.3	53.9 $\pm$ 10.7	15.7 $\pm$ 3.1	4.2 $\pm$ 0.8
$Wb\bar{b}$	306.9 $\pm$ 106.9	144.7 $\pm$ 49.4	30.0 $\pm$ 9.7	6.4 $\pm$ 2.5
$Wc\bar{c}$	63.1 $\pm$ 22.0	43.0 $\pm$ 14.7	8.7 $\pm$ 2.8	1.9 $\pm$ 0.8
Wc	185.7 $\pm$ 47.2	34.4 $\pm$ 9.0	3.4 $\pm$ 0.9	0.6 $\pm$ 0.2
$t\bar{t}$(6.7pb)	6.9 $\pm$ 1.2	42.0 $\pm$ 6.6	84.9 $\pm$ 12.8	98.6 $\pm$ 14.3
Single Top	16.7 $\pm$ 1.8	23.5 $\pm$ 2.4	4.8 $\pm$ 0.5	0.8 $\pm$ 0.1
Diboson/$Z^0 \rightarrow \tau\tau$	11.7 $\pm$ 2.2	14.2 $\pm$ 2.3	3.9 $\pm$ 0.9	1.0 $\pm$ 0.3
non-W QCD	84.2 $\pm$ 14.1	38.9 $\pm$ 6.2	12.1 $\pm$ 2.3	5.5 $\pm$ 1.2
Total Background	814.8 $\pm$ 140.7	394.4 $\pm$ 66.6	163.4 $\pm$ 18.7	118.9 $\pm$ 14.9
Observed Events(=1tag w/ NNtag)	856	421	177	139

TABLE I: Background estimate for events with exactly 1 tight + NN tag. No dijet mass window cut has been applied.

Jet Multiplicity	2jet	3jet	$\geq$ 4jet
Observed Events(Before b-tagging)	14604	2362	646
Mistag	3.5 $\pm$ 0.5	2.0 $\pm$ 0.3	1.2 $\pm$ 0.2
$Wb\bar{b}$	20.3 $\pm$ 7.0	5.7 $\pm$ 1.8	1.0 $\pm$ 0.4
$Wc\bar{c}$	3.3 $\pm$ 1.1	0.4 $\pm$ 0.1	0.1 $\pm$ 0.04
Wc	-	-	-
$t\bar{t}$(6.7pb)	10.4 $\pm$ 2.3	29.5 $\pm$ 6.4	45.5 $\pm$ 9.9
Single Top	4.2 $\pm$ 0.7	1.4 $\pm$ 0.2	0.3 $\pm$ 0.1
Diboson/$Z^0 \rightarrow \tau\tau$	1.2 $\pm$ 0.3	0.3 $\pm$ 0.1	0.1 $\pm$ 0.1
non-W QCD	1.4 $\pm$ 0.3	0.9 $\pm$ 0.2	0.3 $\pm$ 0.1
Total Background	44.2 $\pm$ 8.5	40.1 $\pm$ 6.8	48.6 $\pm$ 10.0
Observed Events($\geq$1tag)	39	44	65

TABLE II: Background estimate in double-tagged events. No dijet mass window cut has been applied.

related to ISR and FSR, halving and doubling the default values. The difference from the nominal acceptance is taken as the systematic uncertainty. Other uncertainties on parton distribution functions, trigger efficiencies, or lepton identification contribute to a smaller extent to the overall uncertainty. The summary of these systematic uncertainties on the signal acceptance is given in Table III.

V. RESULTS

We perform a direct search for a resonant mass peak in the reconstructed dijet invariant mass distribution from the tagged W+2 jet events. A binned maximum likelihood technique is used to estimate upper limits on Higgs production by constraining the number of background events to the estimates within uncertainties.

The many possible variations of b-tagging in the event selection lead to different sensitivities; these results are shown

Source	Uncertainty (%)	
	>= 2 TTag	= 1 TTag+NNtag
Lepton ID	~2%	~2%
Trigger	<1%	<1%
ISR	4.3%	1.8%
FSR	8.6%	3.2%
PDF	2.0%	1.7%
JES	3.0%	2.3%
b-tagging	16%	5.3%
Total	19.1%	7.2%

TABLE III: Systematic uncertainty on the WH acceptance. Effects of limited Monte Carlo statistics are included in these values.

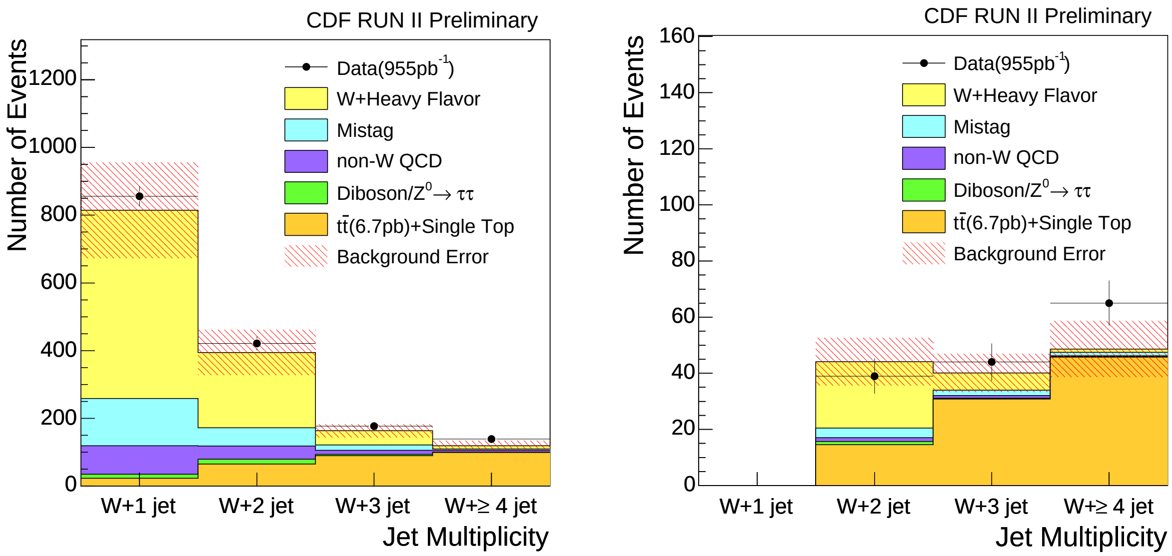

FIG. 2: Predicted and observed W+jet multiplicity with all background contributions. Results are shown for two disjoint selections: exactly 1 NN b-tag (left) and ≥ 2 vertex tags (right).

in Fig. 3. It is clear that the greatest sensitivity to Higgs production and decay comes from the combination of single neural network b-tags and plain double-vertex-tagging. (The light flavor contamination in the double-tag sample is small enough to obviate the additional NN cuts.)

For both of these optimal selections, Fig. 4 shows the dijet mass distribution in the data compared to the expectations from background. The agreement is reasonable, considering the uncertainties in the background distributions. We set an upper limit on the production cross section times branching ratio as a function of m_H, plotted in Fig. 5. The results are also collected in Table IV.

Higgs Mass	Upper Limit (pb)	
GeV/c^2	Observed	Expected
110	3.9	2.2
115	3.4	2.2
120	2.5	2.0
130	1.6	1.8
140	1.4	1.7
150	1.3	1.5

TABLE IV: Observed 95% C.L. upper limit on $\sigma(p\bar{p} \to WH) \times BR(H \to b\bar{b})$

VI. CONCLUSIONS

We have searched in a $955\,\mathrm{pb}^{-1}$ data set for evidence of Standard Model Higgs boson production associated with a W boson. We do not observe any such production in the $H \to b\bar{b}$ mode, and we set upper limits on the production rate times branching ratio. Total rates larger than 3.4 pb are excluded at 95% confidence level for the $115\,\mathrm{GeV}/c^2$ Higgs mass hypothesis, decreasing to 1.3 pb for a $150\,\mathrm{GeV}/c^2$ Higgs. These results represent significant improvement over previous results, but are still limited by the small number of expected Higgs events given the current dataset size and selection efficiency.

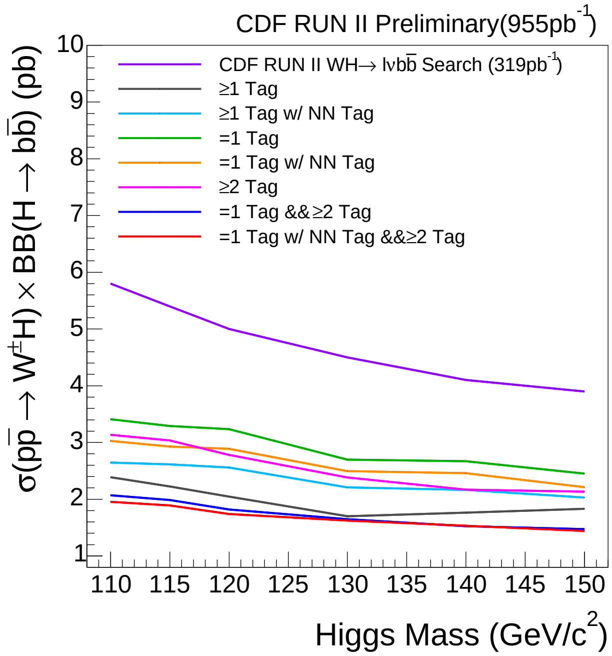

FIG. 3: Expected limits on Higgs production and decay for different b-tagging selection strategies as a function of the Higgs mass hypothesis. The final results combine the ≥ 2 tag and $= 1$ tag w/ NN tag selections for maximum sensitivity.

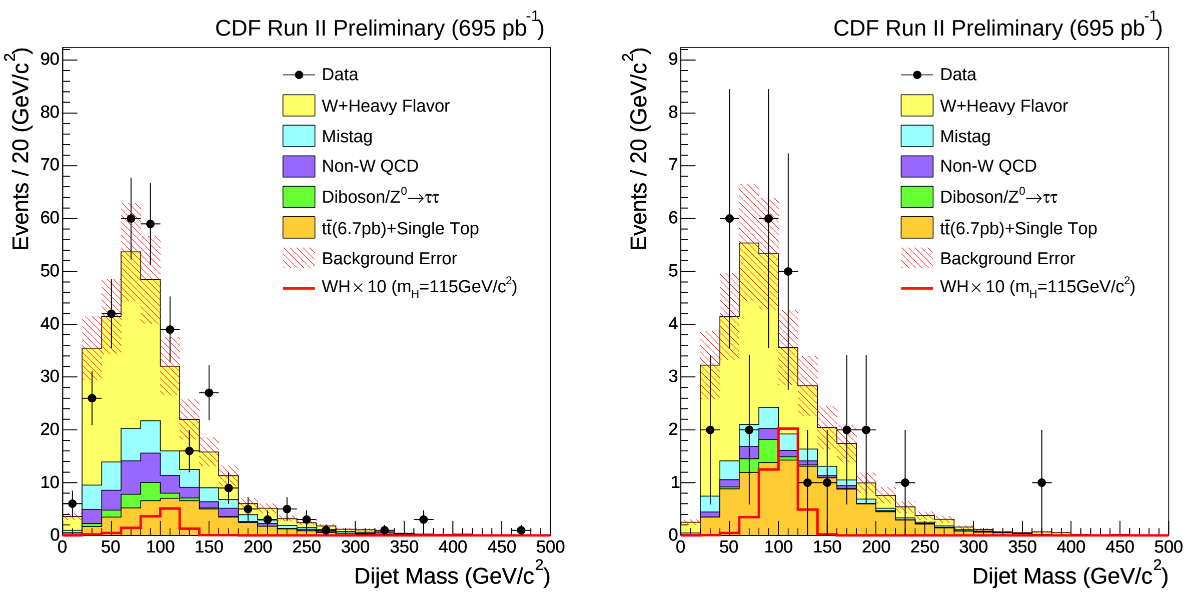

FIG. 4: Predicted and observed dijet mass distributions in W+2-jet events for the cases of exactly 1 NN b-tag (left) and ≥ 2 vertex tags (right).

Acknowledgments

We thank the Fermilab staff and the technical staffs of the participating institutions for their vital contributions. This work was supported by the U.S. Department of Energy and National Science Foundation; the Italian Istituto Nazionale di Fisica Nucleare; the Ministry of Education, Culture, Sports, Science and Technology of Japan; the

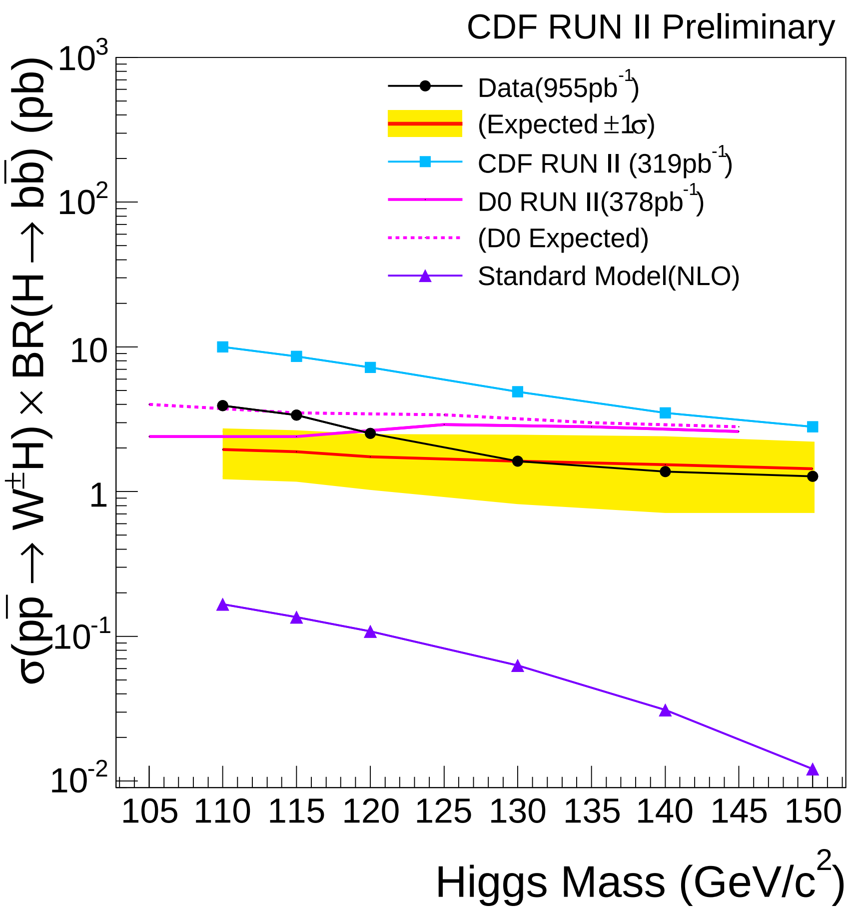

FIG. 5: Observed and predicted rate limits as a function of the Higgs mass hypothesis. These results are based on the combined ≥ 2 tag and $= 1$ tag w/ NN tag selections.

Natural Sciences and Engineering Research Council of Canada; the National Science Council of the Republic of China; the Swiss National Science Foundation; the A.P. Sloan Foundation; the Bundesministerium für Bildung und Forschung, Germany; the Korean Science and Engineering Foundation and the Korean Research Foundation; the Particle Physics and Astronomy Research Council and the Royal Society, UK; the Russian Foundation for Basic Research; the Comision Interministerial de Ciencia y Tecnologia, Spain; and in part by the European Community's Human Potential Programme under contract HPRN-CT-20002, Probe for New Physics.

---

[1] LEP Electroweak Working Group, `http://lepewwg.web.cern.ch/LEPEWWG/`
[2] ALEPH, DELPHI, L3, OPAL. The LEP Working Group for Higgs Boson Searches, Phys. Lett **B565** 61 (2003).
[3] T. Han and S. Willenbrock, Phys. Lett. **B273** (1991) 167;
A. Djouadi, J. Kalinowski, and M. Spira, Comp. Phys. Commun. **108 C** (1998) 56.
[4] A. Abulencia *et al.*, Phys. Rev. Lett. **96** 081803 (2006).
[5] F. Abe, *et al.*, Nucl. Instrum. Methods Phys. Res. A **271**, 387 (1988);
D. Amidei, *et al.*, Nucl. Instum. Methods Phys. Res. A **350**, 73 (1994);
F. Abe, *et al.*, Phys. Rev. D **52**, 4784 (1995);
P. Azzi, *et al.*, Nucl. Instrum. Methods Phys. Res. A **360**, 137 (1995);
The CDF II Detector Technical Design Report, Fermilab-Pub-96/390-E.
[6] A. Abulencia *et al.*, Phys. Rev. **D71**, 072005 (2005).
[7] L. Lönnblad, C. Peterson, and T. Rögnvaldsson, Comp. Phys. Comm. 81 (1994) 185.
[8] M.L. Mangano *et al.*, JHEP 0307:001, 2003.

[9] G. Corcella *et al.*, JHEP 0101 (2001) 010 [hep-ph/0011363]; hep-ph/0210213.
[10] P. Edén, C. Friberg, L. Lönnblad, G. Miu, S. Mrenna, E. Norrbin, and T. Sjöstrand, Computer Phys. Commun. **135** (2001) 238.